Evaluation of Anti-Stripping Agents on Warm Porous Asphalt Mixtures

Mohamad Yusri Aman and Meor Othman Hamzah

Smart Driving Research Centre, Name Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia.

Affiliation school of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia.

ABSTRACT

The presence of water in porous asphalt mixtures detrimentally affects the bonding within the binder and bonding between the binder and the aggregates which is prone to stripping. The purpose of this paper is to evaluate the effectiveness of anti-stripping agents in improving water sensitivity of porous asphalt mixes prepared using Sasobit® modified bitumen. Hydrated lime and a newly developed anti-stripping agent known as Pavement Modifier (PMD) as filler were investigated. Specimens were compacted by applying 35 blows on each face using Marshall Impact compactor at various compaction temperatures. Subsequently, the specimens were tested for their strength, air voids and indirect tensile strength ratio (ITSR). The results indicated that the specimens incorporating PMD exhibit higher ITS and better resistance to water sensitivity compared to specimens containing hydrated lime. It can be concluded that samples prepared with PMD have better resistance to moisture damaged as compared to samples with hydrated lime.

INTRODUCTION

Porous asphalt (PA) is predominantly made up coarse aggregates resulting in air void exceeding 20%. The mix is able to reduce noise level, improves wet weather skid resistance, reduces risk of aquaplaning, and reduce splash and spray (Mo et al., 2009). In Malaysia, PA was first tried on the Cheras-Beranang Road in 1991. PA is able reduce traffic accidents and promote road safety, especially during wet weather (Hamzah et al., 2010a).

The asphalt industry has been exploring ways and means to reduce the energy consumption and poor air quality issue, which contributed to increase in environmental pollution and greenhouse gases (Zaumanis, 2010). In an asphalt plant, Hot-Mix Asphalt (HMA) is typically produced in either batch or drum mix plants, which aggregates normally heated between 138°C to 160°C before being coated with bitumen to achieve desired workability. Continuous aggregate heating increased fuel cost and also contributed to increase in emissions and greenhouse gases (You and Goh, 2008). The Warm Mix Asphalt (WMA) temperature reduction is the result of recently developed technologies in asphalt industries. WMA can be a potential technology that not only lower emissions but reduce energy consumption by reducing the required production temperature (Su et al., 2009).

Sasobit® is one of the earlier warm additive materials that were developed for warm mix technologies. It is produced by Fischer-Tropsch synthesis from coal or natural gas with a long-chain aliphatic hydrocarbon. Incorporating Sasobit®, reduces binder viscosity resulting in decreasing the required mixing and compaction temperatures. Subsequently, these reduce the visible and invisible emissions from burning fumes and odors that can adversely affects the health of construction workers (Janitpong et al., 2008). However, the reduction of mixing temperatures can possibly cause incomplete removal of the moisture from aggregates. This influences the strength of bitumen and aggregates bonding, and promotes moisture damage. The moisture damage is caused by loss of adhesion between aggregate and bitumen coating or loss of cohesion strength in bitumen or bitumen-filler mastic due to the presence of moisture in asphalt mixture and can potentially lead to stripping (Airey et al., 2007). According to Hamzah et al., (2010b), the abrasive action of vehicle wheel on pavement surface, especially on high stressed areas, can initiate particle loss, while the action of water may result in stripping. This leads to a pavement distress type known as raveling and is more predominant in porous asphalt compared to dense asphalt. Hydrated lime is the most commonly used anti-stripping agent to improve the moisture.
susceptibility of asphalt mixes. Lime enhances the bitumen-aggregates bond and improves the resistance of the bitumen to water-induced damage. Hydrated lime with carboxylic acid chemical components absorbed at the aggregate surface in high concentration, increased adhesion bond strength between asphalt binder and aggregates helps to reduce stripping potential, resulted in a more durable pavement (Kok and Yilmaz, 2008; Huang et al., 2005; Aman and Hamzah, 2014).

In the last decade, many studies have been conducted to evaluate the moisture damage of asphalt mixtures and published in literatures. Airey et al., (2007) studied the influence of aggregate, filler and bitumen on asphalt mixture moisture damage in which granite and limestone aggregates were added with crushed granite filler, and hydrated lime as anti-stripping agents, to examine the moisture damage using the saturated aging tensile stiffness test. The results indicated that mixes with hydrated lime exhibit improved moisture susceptibility compared to those with crushed granite filler. This was evident from the higher retained stiffness value. Wang et al., (2010) conducted an investigation on the use of strip-prone aggregates in hydraulic asphalt concrete. This study involved the use of asphalt concrete as a water barrier in embankment dams and tested using indirect tensile test. The results indicated that the aggregate-bitumen adhesion and tensile strength can be increased by adding hydrated lime to the asphalt mix. Huang et al., (2005) investigated the impact on moisture sensitivity resistance of asphalt mixtures prepared with limestone and granite aggregates and the addition of hydrated lime directly to the asphalt prior to mixture, and evaluated by freeze-thaw cycling of the mixtures in water, while Aman and Hamzah, (2014) conducted study to assess moisture damage of asphalt mixtures containing hydrated lime and a newly developed anti-stripping agent known as Pavement Modifier (PMD) and tested with indirect tensile test. The objective of this paper is to investigate the effects of Sasobit® on porous asphalt prepared using conventional hydrated lime and the newly developed anti-stripping agent namely Pavement Modifier (PMD) which were mixed and compacted at various temperatures.

MATERIALS AND METHODS

For the evaluation of anti-stripping agents on the warm mix porous asphalt, the hydrated lime and PMD used were supplied from a local source while the Sasobit® was imported from Sasol Wax, South Africa. A conventional bitumen 60/70 penetration grade was used as the base binder. The crushed granite aggregate which was obtained from a local quarry were washed, dried and sieved in selected size ranges according to the proposed aggregate gradation. The results of the sieve analysis are shown in Table 1. In this study, two anti-stripping agents, namely hydrated lime and a newly developed anti-stripping agent known as Pavement Modifier (PMD) were used as filler. Two porous asphalt mix designs were prepared to incorporate of 2%, 3% and 5% hydrated lime, lime stone dust and PMD, respectively.

Table 1: Aggregate gradation.

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>Percent passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>80.0</td>
</tr>
<tr>
<td>5</td>
<td>21.5</td>
</tr>
<tr>
<td>2.36</td>
<td>10.0</td>
</tr>
<tr>
<td>0.425</td>
<td>7.0</td>
</tr>
<tr>
<td>0.075</td>
<td>5.0</td>
</tr>
</tbody>
</table>

A. Mixing and Compaction Temperatures:

The viscosity of asphalt binder at high temperatures is an important factor that determines the binder’s ability to coat the aggregates during mixing in asphalt mixture. A Brookfield Rotational Viscometer (RV) was used to determine the mixing and compaction temperatures of conventional 60/70 bitumen penetration grade incorporating 1% Sasobit® according to ASTM D4402 (ASTM, 2005) procedures. Figure 1 show the semi-logarithmic relationship between viscosity and temperature for binder blended with 1% Sasobit®, while temperatures range adopted for mixing and compaction are represented by the dashed and dotted lines. The result indicates that the required mixing and compaction temperatures were found to be 155°C and145°C, respectively. Therefore, to determine effects of anti-stripping agents used on moisture sensitivity of warm PA mixes, the mixing and compaction temperature were reduced as low as 125°C and 115°C, correspondingly.
Fig. 1: Mixing and compaction temperatures.

B. Specimen Preparation:

The upper and lower limit’s design binder content were determined according to the binder drainage test and Cantabro test as described in the British Transport Research Laboratory (TRLL) by Daines, (1992) and by Jimenez and Perez, (1990), respectively. From the tests, the design binder contents for both porous mixes incorporating hydrated lime and PMD fillers were selected at 4.7% and 5.4%, respectively. The aggregates and asphalt binder were mixed at the corresponding mixing temperature. According to the Asphalt Institute (2007) procedures, the loose hot mixes were conditioned in an oven for two hours at the compaction temperature before compaction. Based on BS EN 12697-12 (BS EN, 2008) procedures, the specimens were compacted by applying 35 blows per face. The specimens were cooled overnight at ambient temperatures before extrusion of the specimens from the moulds.

C. Resistance to Water Sensitivity:

The testing procedure described herein followed BS EN 12697-12 (BS EN, 2008) procedures for the determination of water sensitivity of bituminous mixtures. Two subset compacted specimens were prepared for subsequent conditioning and un-conditioning procedures. The conditioned specimens were submerged in water at 25°C for 20 minutes before application of the pressure vacuum at 6.7 kPa for 10 minutes and the vacuum maintained for 30 minutes. Subsequently, the specimens were submerged for another 30 minutes in water before conditioned in a water bath at 40°C for 70 hours, while similar number of specimens were left at 20°C in an incubator for a similar period of time. Upon subjected to wet conditioning, the specimens were pre-conditioned at 20°C in a water bath for four hours before testing for indirect tensile strength according to the ASTM D4123 (ASTM, 2005) procedures. The ITS was calculated using Equation (1).

\[
\text{ITS} = \frac{2000F}{\pi hd}
\]

Where;

- \(\text{ITS}\) = Indirect Tensile Strength (kPa)
- \(F\) = Maximum applied load (N)
- \(h\) = Specimen thickness (mm)
- \(d\) = Specimen diameter (mm)

Mix resistance to the effects of water was calculated from the ratio of the ITS of moisture-conditioned to the ITS unconditioned samples calculated using Equation (2). According to the BS EN 12697-12 (BS EN, 2008) procedure, the minimum acceptable ITSR is 77%.

\[
\text{ITSR} = \frac{\text{ITS}_{\text{wet}}}{\text{ITS}_{\text{dry}}} \times 100
\]

Where;

- \(\text{ITSR}\) = Indirect tensile strength ratio (%)
- \(\text{ITS}_{\text{wet}}\) = Average indirect tensile strength of the wet group (kPa)
- \(\text{ITS}_{\text{dry}}\) = Average indirect tensile strength of the dry group (kPa)
D. Air Voids Determination:

The air voids for porous specimen should be high enough to ensure sufficient permeability. According to the Malaysian Public Works Department (JKR, 2008), specifications for porous asphalt, the air voids content should be greater than 18%. The bulk specific gravity of a compacted specimen \( G_{mb} \) was ascertained using the specimen geometry method obtained by measuring its diameter, heights and mass of the specimens in the air. The theoretical maximum density \( G_{mm} \) determination of the loose mix was carried out according to ASTM D2041 (ASTM, 2005) procedures. Air voids in the compacted specimens was calculated using Equation (3).

\[
V_a = 100x \left(1 - \frac{G_{mb}}{G_{mm}}\right) 
\]

Where:
- \( V_a \) = Air voids
- \( G_{mb} \) = Bulk gravity of a compacted specimen
- \( G_{mm} \) = Theoretical maximum density

E. Coefficient of Permeability:

Permeability tests were conducted on compacted samples using a falling head permeameter based on the design by Hamzah (1995). The coefficient of permeability \( k \) of porous asphalt was conducted on compacted specimens before being extruded from the Marshall mould. The hydraulic conductivity equipment was fabricated from a cylindrical Perspex tube glued to a thick Perspex base. Water was poured into the Perspex tube and allowed to permeate through the specimen. Time was recorded for the water level to drop from two designated points on the permeameter. The coefficient of permeability \( k, \text{cm/s} \) was calculated using Equation (4).

\[
k = \frac{2aL}{A_t} \log_{10}\left(\frac{h_1}{h_2}\right) 
\]

Where:
- \( k \) =Coefficient of permeability (cm/s)
- \( A \) = Cross section area specimens (cm2)
- \( a \) = Cross section area standpipe (cm2)
- \( L \) = Height of specimens (cm)
- \( t \) = time taken for water in the standpipe to fall from \( h_1 \) to \( h_2 \) (s)
- \( h_1 \) = water level at \( t_1 \) (cm)
- \( h_2 \) = water level at \( t_2 \) (cm)

The laboratory test results of this study were further analyzed by using statistical analysis. An analysis of variance (ANOVA) was performed to determine if the effect of factors were statistically significant at 5% significant level.

RESULT AND DISCUSSION

A. Air Voids:

The air voids of porous specimens prepared with hydrated lime and Pavement Modifier (PMD) in relation to compaction temperature is shown in Figure 2. The results indicate a general increasing trend of the air voids as compaction temperature decreases. The air void of specimens incorporating PMD and hydrated lime are increased by 15.7% and 13.9%, respectively as compaction temperature decreases. When compaction temperature decreases, the binder becomes more viscous and stiffer, making it difficult to compact and subsequently resulting in higher mix air voids which lead to increase air void between binders coated aggregate particles. However, the air voids for all specimens tested conformed to the Public Works Department (PWD, 2008) specifications for porous asphalt, which recommend a limiting value of 18%. Specimens incorporating PMD exhibit lower air voids compared to mix with hydrated lime filler. The air voids of specimens incorporated PMD are decreased by 4.9% and 3.0% at 145°C and 115°C compaction temperatures, respectively. The results are similar to that of Hamzah et al., (2011), which indicated that decreasing the compaction temperature increased the air voids in asphalt mixtures.
The significance of the increased of air voids in the specimens incorporating anti-stripping agent and compaction temperature was examined statistically at 95% confidence level. Table 2 shows the results of a two-way analysis of variance which indicates that the anti-stripping agent and compaction temperature have significant effects on the air voids with p-value less than 0.05. However, the interaction between the two factors shows otherwise.

### Table 2: Two-way ANOVA effect on air voids.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-stripping</td>
<td>1</td>
<td>7.576</td>
<td>7.575</td>
<td>11.25</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Compaction Temperature</td>
<td>3</td>
<td>95.691</td>
<td>31.897</td>
<td>47.37</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Interaction</td>
<td>3</td>
<td>1.031</td>
<td>0.343</td>
<td>0.51</td>
<td>0.677</td>
</tr>
<tr>
<td>Error</td>
<td>40</td>
<td>26.934</td>
<td>0.673</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>131.232</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### B. Indirect Tensile Strength:

The indirect tensile strength (ITS) results of the unconditioned mix incorporating Sasobit® prepared with hydrated lime and PMD fillers is shown in Figure 3. The bar chart clearly shows that the ITS decreases as compaction temperature decreases for all specimens regardless filler types. It can be seen that specimens incorporating PMD exhibit higher ITS compared to specimens incorporating hydrated lime. The ITS values for PMD incorporated specimen are increased by 2.9% and 3.4% at 145°C and 115°C compaction temperatures, respectively. As discussed in Section 2.2, specimens incorporating PMD were mixed with high binder content compared to hydrated lime. As so, this high binder content contributes to thicker binder film's thickness which increase ITS values. However, the decreased of compaction temperature has significantly decreased the ITS of both mixes type. Low compaction temperature which causes high binder viscosity has compromised effective binder coating and results inadequate compaction. The increased of air voids produced low tensile strength mixes. According to Aman and Hamzah (2014), the reduction in compaction temperature significantly decrease the ITS values. Low compaction temperature, which causes high binder viscosity, compromises the effective binder coating and results in inadequate compaction. The increase in air voids produces low tensile strength mixes.

Table 3 shows the result of ANOVA analysis for specimens incorporating hydrated lime and PMD at 5% significant level. The results show that PMD filler and compaction temperature are significantly influenced the ITS values. The results also indicate that there is no significant interaction between PMD and the compaction temperature.

### Table 3: Two-way ANOVA results on ITS.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-stripping</td>
<td>1</td>
<td>2157.8</td>
<td>2157.8</td>
<td>7.82</td>
<td>&lt;0.013</td>
</tr>
<tr>
<td>Compaction Temp.</td>
<td>3</td>
<td>41073.7</td>
<td>13691.2</td>
<td>49.61</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Interaction</td>
<td>3</td>
<td>102.4</td>
<td>34.1</td>
<td>0.12</td>
<td>0.945</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>4415.7</td>
<td>276.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>47749.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A tensile strength (ITS) test was performed to measure the sensitivity of asphalt mixtures incorporating hydrated lime and PMD as an anti-stripping agent on water conditioning. Figure 4 presents the indirect tensile strength ratio (ITSR), which is defined as the ratio of the ITS of wet specimen to dry specimen. For a given compaction temperature, the ITSR of the PMD mixes is always higher than the hydrated lime mixes. By incorporating PMD, the ITSR increased by 4.9% and 11% at 145°C and 115°C compaction temperatures, respectively. Furthermore, specimens incorporating PMD exhibit higher ITSR and better resistance to water damage compared to the specimen containing hydrated lime. This improved moisture resistance is due to the presence of carbonaceous compounds in the PMD which enhance the adhesion of the binder coating onto the surface of the aggregates. According to Aman (2013), specimens prepared with PMD filler can potentially improve resistance to stripping of PA mixes compared to hydrated lime regardless of compaction temperature. This effect can probably due to PMD containing calcium oxide, which increases the interaction between the aggregate surface and the bitumen binder to improve the bond between the bitumen and the aggregate compared to the hydrated lime containing calcium carbonate.

The reduction in compaction temperature has adversely affects mix susceptibility to water damage. This is due to incomplete drying and entrapment of moisture in aggregates during heating and mixing at lower temperature. The lower compaction temperature has also induced high binder viscosity and inferior binder coating. BS EN 12697-12 (2008), limits the ITSR for water sensitivity to be not more than 77%. Therefore, the PMD filler is able to sustain this ITSR at compaction temperature 125°C. The corresponding temperature for the hydrated lime mixes is 135°C. The results show the superior performance of the PMD mixes to resist water damage despite low compaction temperature.

![Fig. 3: Indirect tensile strength test results.](image)

**C. Water Sensitivity of Porous Asphalt:**

The indirect tensile strength (ITS) test was performed to measure the sensitivity of asphalt mixtures incorporating hydrated lime and PMD as an anti-stripping agent on water conditioning. Figure 4 presents the indirect tensile strength ratio (ITSR), which is defined as the ratio of the ITS of wet specimen to dry specimen. For a given compaction temperature, the ITSR of the PMD mixes is always higher than the hydrated lime mixes. By incorporating PMD, the ITSR increased by 4.9% and 11% at 145°C and 115°C compaction temperatures, respectively. Furthermore, specimens incorporating PMD exhibit higher ITSR and better resistance to water damage compared to the specimen containing hydrated lime. This improved moisture resistance is due to the presence of carbonaceous compounds in the PMD which enhance the adhesion of the binder coating onto the surface of the aggregates. According to Aman (2013), specimens prepared with PMD filler can potentially improve resistance to stripping of PA mixes compared to hydrated lime regardless of compaction temperature. This effect can probably due to PMD containing calcium oxide, which increases the interaction between the aggregate surface and the bitumen binder to improve the bond between the bitumen and the aggregate compared to the hydrated lime containing calcium carbonate.

The reduction in compaction temperature has adversely affects mix susceptibility to water damage. This is due to incomplete drying and entrapment of moisture in aggregates during heating and mixing at lower temperature. The lower compaction temperature has also induced high binder viscosity and inferior binder coating. BS EN 12697-12 (2008), limits the ITSR for water sensitivity to be not more than 77%. Therefore, the PMD filler is able to sustain this ITSR at compaction temperature 125°C. The corresponding temperature for the hydrated lime mixes is 135°C. The results show the superior performance of the PMD mixes to resist water damage despite low compaction temperature.

![Fig. 4: Indirect tensile strength ratio for porous asphalt.](image)

A two-way analysis of variance (ANOVA) was performed to analyze the effects of anti-stripping agent on water sensitivity of porous asphalt incorporating Sasobit® at various compaction temperatures at 5% significant
level. The result summarized in Table 4, shows that anti-stripping agent type and compaction temperature are significant parameters contributing to the effect on ITSR. The statistical analysis also indicates that there is no significant interaction effect between anti-stripping agent type and compaction temperature.

Table 4: Two-way ANOVA on ITSR of porous asphalt.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-stripping</td>
<td>1</td>
<td>220.55</td>
<td>220.55</td>
<td>11.23</td>
<td>&lt;0.004</td>
</tr>
<tr>
<td>Compaction Temperature</td>
<td>3</td>
<td>1084.95</td>
<td>361.65</td>
<td>18.42</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Interaction</td>
<td>3</td>
<td>15.88</td>
<td>5.295</td>
<td>0.27</td>
<td>0.846</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>314.11</td>
<td>19.632</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>1635.50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D. Effect of Air Voids on Indirect Tensile Strength:

Figure 5 illustrates the effects of air voids on ITS of unconditioned specimens incorporating hydrated lime and PMD. The result shows a general decreasing trend of the ITS as the air voids increases. It can be concluded that the porous specimens incorporating PMD exhibit higher ITS compared to specimens prepared with hydrated lime.

Based on Figure 5, by incorporating PMD, the air voids correspondingly increased by 6.8 % and 3.4% at 145°C and 115°C compaction temperature resulted decreasing the ITS by 2.8% and 3.3%, respectively. These were due to the specimen incorporating PMD was designed with high binder content. At higher binder content, the aggregates in the mix are fully coated with thicker asphalt film thickness and consequently reduce the air voids. However as binder viscosity increases due to low compaction temperature, the air voids increases. The results can be supported by finding from Aman (2013), which porous specimens incorporating PMD exhibit higher ITS values than the specimens prepared with hydrated lime. By incorporating PMD, the air voids correspondingly increase as compaction temperatures increases, resulting in the decrease of ITS. This is because the specimen incorporating PMD was designed with higher binder content. At higher binder content, the aggregates in the mix are fully coated with thicker asphalt film, consequently reducing the air voids. However, as the binder viscosity increases due to low compaction temperature, the air voids increase.

A One-Way Analysis of Variance was used to identify whether air voids has a significant effect on the ITS of porous specimens at 5% significant level. From Table 5, the p-value is less than 0.05., hence the air voids have significant effects on ITS.

Table 5: One-Way ANOVA Effect of Air Voids on ITS.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>46662.940</td>
<td>19</td>
<td>2455.944</td>
<td>8.825</td>
<td>&lt;0.024</td>
</tr>
<tr>
<td>Within Groups</td>
<td>1113.135</td>
<td>4</td>
<td>278.284</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>47776.065</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

E. Relationship between Air voids and Coefficient of Permeability:

Figure 6 illustrates a scatter plot showing the relationship between air voids and coefficient of permeability for specimens incorporating PMD and hydrated lime fillers. The curve was plotted using quadratic regression.
relationship for both specimens incorporating PMD and hydrated lime where the coefficient of permeability \(k\) is correlated to air voids with correlation coefficient more than 0.7. In general, \(k\) increases as air voids increases. Specimens incorporating PMD give a low coefficient of permeability compared to hydrated lime specimens. The curve also shows a general tendency for \(k\) to increase at a higher rate as the air voids increases. With high air voids, surface water can be quickly removed through the pore structures. The resultant coefficient of permeability depends on the air voids continuity, and which is highly prevalent in a porous mixture.

![Graph showing relationship between air voids and coefficient of permeability](image)

**Fig. 6: Relationship between Air voids and Coefficient of Permeability.**

According to Liu and Cao (2009), there are two types of air voids, connected and isolated air voids, which influence the efficiency of drainage for porous asphalt. The connected air voids form minute drainage channels allowing water of flow through, while the isolated or closed air voids are formed within the asphalt mixture and as a result there is no opening to the air. Mallick et al., (2000) recommended a minimum coefficient of permeability for porous asphalt at least 0.116 cm/s to provide sufficient drainage. All mixes in this study exhibit coefficient of permeability higher than the recommended value. However, the coefficient of permeability will be low with the dominance of closed air voids compared to the connected air voids. The connected air voids are more effective to drain the water through its pore structure. From the scatter of results, the coefficient of permeability of mixes can be different even though the percentage of air voids is similar.

**Conclusion:**

Porous asphalt containing hydrated lime and PMD as fillers and anti-stripping agents compacted at different temperatures were evaluated for their resistance to water sensitivity mix. Low mixing temperatures may prevent moisture from being completely evaporated from the aggregates and making the mix adversely prone to stripping. From this study, it can be concluded that porous specimens incorporating PMD exhibit higher ITS, better resistance to water damage but lower air voids compared to mixes incorporating hydrated lime. It is also found that as compaction temperature decreases, the air voids and coefficient of permeability increase. This can be explain in terms of increased binder stiffness as its temperature reduces, making it more difficult to compact. Incorporating Sasobit® in the porous mixes decreases ITS irrespective of anti-stripping agent type used.

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**REFERENCES**


